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"Effects of Io's Extended SO_2 atmosphere on the Plasma Torus of Jupiter"

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This report summarizes the results obtained from an investigation of the effects of neutral SO_2 molecules on the composition and energy budget of the Io plasma torus. The subject of the torus has been of prime interest for many researchers as it provides the bulk of matter to the magnetosphere in the form of heavy ions and has a major influence on the global magnetospheric dynamics. Moreover, it is readily observable from ground-based telescopes and can be monitored over the long term for indications of change. The Io torus thus occupies a unique position in science being on one hand a highly luminous astrophysical type body that is visible over a wide range of wavelengths and on the other an object that is accessible to in situ measurements by spacecraft to test and confirm not only theory but also conclusions obtained by remote sensing.

The theory for the maintenance of the Io torus, in particular the energy budget for the intense radiation emanating from it, has met with much controversy over the last several years. Several researchers, most notably D.E. Shemansky (Univ. of Arizona) have insisted that so-called neutral cloud theory (NCT), which is the standard model for the Io torus ionization and energy balance, is not correct. The justification for their position derives from a computer model which predicts a very small electron temperature and a correspondingly low ionization state (predominantly singly ionized) in contradiction to Voyager observations. The conclusion they draw is that therefore the fundamental hypothesis on which their calculations are based (NCT) is false, although they do not suggest any alternative model. One of the primary observational results on which their claim is based is the lack of detectable emission from OIII which is predicted by NCT to have a concentration of $\sim 40cm^{-3}$ in the warm torus.

Recently, several new observations have clarified the issues considerably. UV observations of the warm torus by the Hopkins Ultraviolet telescope (HUT) have shown a positive detection of OIII with a density $40cm^{-3}$ confirming the prediction of NCT. Also, a long overdue analysis of some Voyager in situ plasma measurements in the middle magnetosphere shows evidence for the presence of O^{2+} which has been transported outwards from the warm torus, thus providing additional independent support for a critical prediction of NCT. In light of these developments it is fair to say that neutral cloud theory on which this research project is firmly rooted has been reinvigorated by the new observations notwithstanding the sound theoretical arguments that have been made all along in support of it but dismissed out of hand by the naysayers.

The following is a description of papers presented at meetings and written reports that have been supported by NAGW-1810:

D.D. Barbosa, Energy balance of the cold and hot Io tori, paper presented at the XXVIII Plenary Meeting COSPAR, The Hague, Netherlands, June 25-July 6, 1990.

ABSTRACT

Fifteen years after its discovery, the Io plasma torus is still a subject of intense controversy. At first, its very existence was challenged. Later, the debate moved to the precise composition of ion species. Most recently, the issue of the EUV power source has been revived and the standard model of the Io torus, so-called neutral cloud theory, has come under attack again as an improper description of the radiation physics and chemistry of the torus.

This talk will review the essential elements of neutral cloud theory construed in its broadest sense and attempt to isolate the crux of the energy deficit problem as presently perceived. It is important to distinguish between the matter of the torus heat source (e.g., ion pickup) and the matter of the ion-electron energy transfer process. Theoretical omissions in the latter category (i.e., neglect of hot electrons generated by pickup ions and proton contributions to the energy transfer) can muddle the more general issues of the heat source and ionization balance of the torus. We summarize all important reactions that affect the pickup ion energy budget in the hot and cold tori treated as distinct but interrelated entities. Some new results on Io torus variability will also be presented.

This paper gives a detailed account of all pertinent energy sources for the torus resulting from ionization of Io's neutral clouds (including the SO_2 molecular cloud) and pickup by the corotating plasma flow. The energy balance equation for electron temperature is then solved with the above sources and UV radiation as an energy sink. If allowance is made for the presence of a population of superthermal ($\sim$ keV) electrons which produces a higher average charge state for the heavy ion plasma, then the thermal electron temperature can be successfully predicted by the model. Another prediction from the NCT approach concerns the relative abundance of minor ions like S^{3+} and O^{2+}. As noted previously new observational results have been obtained which confirm the presence of O^{2+} with a density $\sim 40 cm^{-3}$ in agreement with the NCT model calculations. Inasmuch as all other ion species/charge have already been confirmed by observations, this latter finding concerning O^{2+} removes the last obstacle to a complete vindication of Io neutral cloud theory in the face of strenuous objection over the last few years.

M.A. Moreno and D.D. Barbosa, On the energy balance of Io's hot plasma torus: the effects of the molecular SO_2 cloud and the role of sodium ions, EOS Trans. AGU, 70, 1283, 1989.

ABSTRACT

We address the energy deficiency problem in the hot torus by investigating the effects of a neutral molecular SO_2 cloud, the role of sodium ions, the interaction of torus plasma with a molecular cloud near Io and the inhomogeneities of plasma distribution. We investigate the properties of an extended SO_2 cloud in the hot plasma torus and find that the energy contribution to the torus from its interaction with the plasma is not negligible. On the basis of Voyager in situ measurements a model of the torus is developed with two sectors: one with an electron density $n_e=2000 cm^{-3}$ and 3% of a total volume $V_T=4.2 \times 10^{31} cm^3$ and one with $n_e=1000 cm^{-3}$ and a volume 27% of V_T. With a source rate of neutrals of $\rho(SO_2)=2 \times 10^{28} s^{-1}$ the extended neutral SO_2 cloud together with the atomic sulfur and oxygen clouds can supply ~ 0.2 eV $cm^{-3}s^{-1}$ to the torus in the form of newly ionized hot pickup ions. We investigate the effect of sodium pickup ions in the high luminosity region of the torus and find that sodium can supply ~ 0.1 eV $cm^{-3}s^{-1}$. Thus, the total contribution from the interaction of the plasma with the molecular SO_2 extended cloud, the atomic S and O clouds and with neutral sodium adds to ~ 0.3 eV $cm^{-3}s^{-1}$ which is comparable to the radiative emissivity of the torus in the EUV. We also develop a model of the neutral molecular SO_2 cloud near Io having the form $n(SO_2)=10^6/r^{2.3} cm^{-3}$ with r in

units of Io radii. Subsequently, we calculate the power supplied to the torus via its interactions with the magnetospheric plasma and find that for $1.3\ R_{Io} < r < 20\ R_{Io}$ or $\sim 0.5 R_J$, the power is $\sim 7.5 \times 10^{11}$ Watts. It is concluded that the apparent energy deficit of the hot torus arises as the result of not accounting for the molecular SO_2 cloud, its chemistry, sodium pickup ions and the Voyager in situ measurements of the spatial inhomogeneities in the distribution of the plasma.

This paper examines the effects of neutral SO_2 and its dissociation products on the energetics of the torus in a quantitative model that includes spatial inhomogeneities resulting from the short lifetimes that some of the species have. Sodium is one example of an element that should exhibit a localized high concentration of Na^+ ions in a restricted range of L shells near Io's orbit. The enhanced ionization rate of sodium occurring in a localized region can have an influence on the energy budget in a way that is not possible if the newly created Na^+ pickup ions were spread out over the entire volume of the warm torus. This paper considers all the consequences that the large variation in lifetimes of the many components that make up Io's extended neutral cloud have on the brightness profile and composition of the plasma torus with special attention to small scale inhomogeneities. A theoretical model of Io's atmospheric corona is also developed making use of Voyager electron data which show a decrease in electron temperature due to electron-neutral collisions in the vicinity of the Io flux tubes. A written report has been prepared of this work and will be submitted for publication after a polished final draft has been completed.